

# SOIL DEVELOPMENT IN SANDY MATERIALS OF THE BELGIAN CAMPINE

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## INTRODUCTION

During the cartography of the sandy soils of the Belgian Campine - generally characterized by a pronounced podzolisation - a great complexity was found in their morphology.

This paper is an attempt towards genetic classification of the sandy podzols. In an earlier paper (De Coninck and Laruelle, 1960), some preliminary results of this study have already been published. The present work is based mainly on detailed field observations and on micromorphological studies of thin sections.

## PRELIMINARY REMARKS

In order to make the text easier to understand, we give here the definitions of some of the terms used:

The terms *skeleton* and *plasma* of the soil are used in the sense of Kubiena (1938): *Skeleton* includes principally the slightly or unaltered mineral grains and the undigested organic remnants; *plasma*, which forms the essential element of soil dynamics, includes humic matter, clay minerals, and free oxides or hydroxides, especially of iron.

Regarding terminology for the organic matter, we refer to Jongerius (1957): *Moder* is composed of excretions of small soil fauna, with the exception of the earthworms; *mull-like moder* is composed of moder and fine mineral particles; *dispersed humus* is colloidal humic matter liberated at the top of the profile and deposited at some depth in the form of humus skins or "cutans" on the skeleton grains (the term *cutan* is used in the sense of Brewer, 1960).

For the denomination of the genetic horizons, we follow mainly the Soil Survey Staff, U.S.D.A. (1960):

A2 : a mineral horizon in which the feature emphasized is loss of clay, iron or aluminium, with resultant concentrations of quartz or other resistant minerals in sand or silt sizes.

B2 : that part of the horizon where the properties, on which the "B"-horizon is based, are without clearly expressed subordinate characteristics, indicating that the horizon is transitional to an adjacent overlying A- or an adjacent C-horizon.

B2t : B-horizon of (illuvial)<sup>1</sup> clay.

<sup>1</sup>We use "illuvial" between brackets to indicate that in this case B-horizons do not necessarily contain illuviated matter.

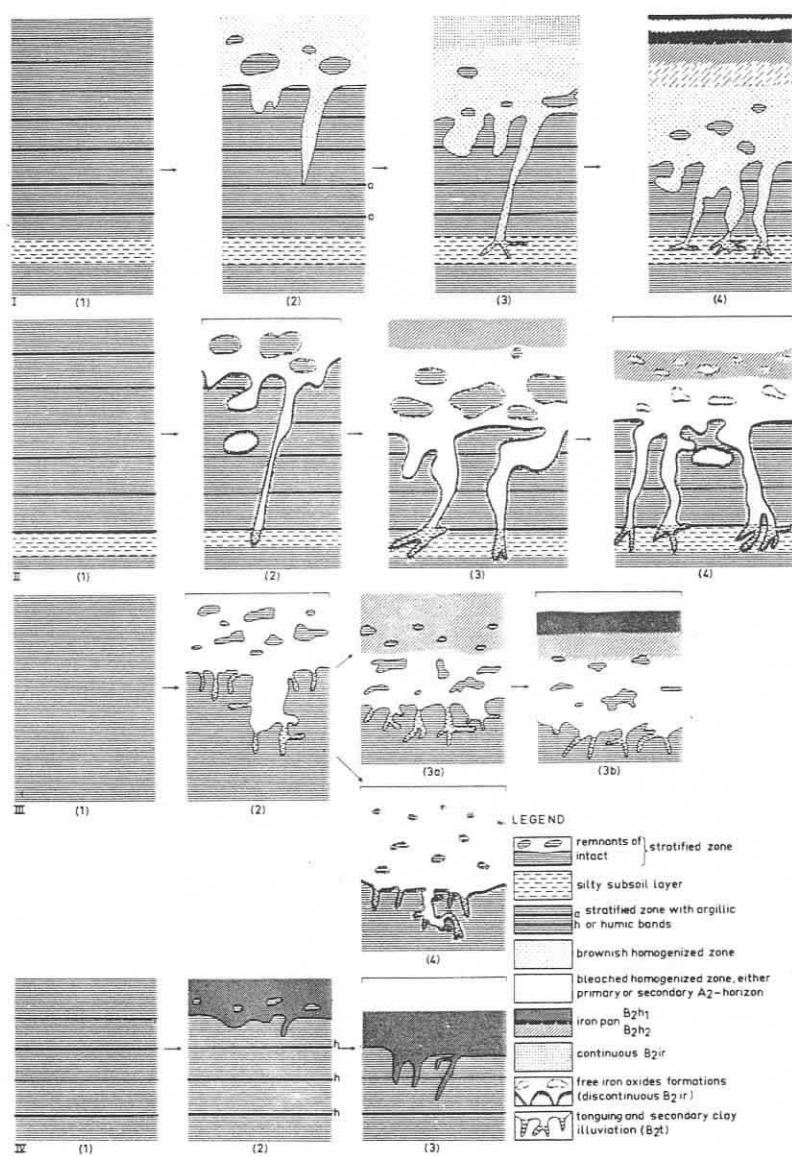


Fig.1.

*I. Sequence of dry soils with brownish plasma*

- (1) Primary clay enrichment.
- (2) Homogenization: brownish homogenized zone.
- (3) Formation of a diffuse B2ir-hor. in the brownish homogenized zone; secondary clay illuviation.
- (4) Formation of a podzol with B2h1- and B2h2-hor.

*II. Sequence of wet soils with brownish plasma*

- (1) Primary clay enrichment.
- (2) Homogenization : formation of a bleached A2- and discontinuous B2ir-hor.; secondary clay illuviation.
- (3) Beginning illuviation of organic matter.
- (4) Formation of a B2h-hor. around mottles and concretions.

*III. Sequence of soils with greenish plasma*

- (1) Primary clay enrichment.
- (2) Homogenization : formation of a bleached A2; secondary clay illuviation.
- (3a) Formation of B2h2-hor. in bleached A2-hor.
- (3b) Evolution to a profile with an A2-, a bleached B2h1- and a brownish B2h2-hor.
- (4) Formation of mottles and concretions.

*IV. Sequence in soils with a primary podzol*

- (1) Primary organic matter enrichment (B2h2-hor.).
- (2) Homogenization : formation of a B2h1-hor.
- (3) Evolution to a profile with a bleached A2-, a blackish B2h1- and a brownish B2h2-hor.

B2ir : B-horizon of (illuvial) iron.

B2h : B-horizon of (illuvial) humus.

B2h1 : upper B-horizon of humus with blackish or grayish color.

B2h2 : lower B-horizon of humus with brownish or reddish-brown color.

The term *homogenization* is used to indicate the process involving disturbance of the original stratification. It is mainly due to the activity of burrowing fauna and of roots (Hoeksema, 1953; Edelman, 1960). The phenomenon is predominantly located in the upper part of the soil profile.

By the term *clay* is meant the fraction less than  $2 \mu$ , as determined by particle size distribution analysis. It does not necessarily mean that this fraction is composed of clay minerals.

*Soil consistency* is named in accordance with the terminology of the Soil Survey Manual (Soil Survey Staff, U.S.D.A., 1951).

The term *podzolization* is used in a rather limited sense: it indicates, the illuviation of organic matter and the formation of B2h-horizons.

The phenomena described in this paper include all soils of the region except the alluvial soils with a permanently high water table.

The distinction between dry and wet soils is based on the absence or presence of a periodic or permanent water table in the profile. In dry soils, the profile never undergoes the influence of a water table. In wet soils, influence of a water table may be permanent or periodical.

#### ORIGIN AND COMPOSITION OF THE PARENT MATERIAL

The sandy deposits dating from the last glaciation and the postglacial period show a more or less horizontal stratification. The texture varies from coarse sand with a mediane around 200  $\mu$  to very sandy loam with 35–50% silt.

The mineralogical composition exhibits a striking difference between south and north. In the southern Campine, where the substratum is composed of glauconitic sands of the Upper Tertiary, the Quaternary deposits always contain a variable percentage of glauconite; in the northern Campine, where the substratum consists of non-glauconitic Lower Pleistocene deposits, the parent material is almost free of glauconite.

#### STAGES OF DEVELOPMENT

The following stages of development have been distinguished:

Stage A : formation of a primary colloidal enrichment;

Stage B : homogenization of the profile and formation of secondary clay;

Stage C : formation of an iron or humus B-horizon;

Stage D : formation of mottles and concretions in soils with greenish plasma.

An overall picture of the soil sequences which can originate in this way, is given in Fig.1.

*Stage A : Primary colloidal enrichment*

The first stage of development seems to consist of a formation of a cutan of plasma around every skeleton particle. This plasma may be organic or mineral.

The organic cutan occurs in specific wet soils, namely those located in small isolated depressions. These soils thoroughly show cutans of dispersed humus, especially expressed as subhorizontal darker bands in case of strong accumulation. In this case, the original stratification of the sediment becomes very obvious. The depth of humus illuviation may be considerable (several meters). The consistency is normally firm, even very firm in some cases. In thin sections, a continuous isotropic brownish cutan of dispersed humus is striking. It may sometimes overlie a very thin birefringent cutan. This humus illuviation forms a B<sub>2h2</sub>-hor.

In all other soils, an oriented birefringent clay cutan is found around the skeleton particles. There may be successive translocation of clay, giving rise to the well-known horizontal bands or lamellae of clay accumulation.

The color of this clay cutan differs strikingly. In dry non-glaucconitic soils, the plasma is brownish; under the influence of a water table, the color turns rusty, although the difference with that of the dry soils may be small.

In dry glauconitic soils, the color is generally comparable to that of dry non-glaucconitic soils. However, it may be distinctly greenish, especially when the glauconite content is high. In wet conditions, there is a general tendency towards a greenish color, although many soils keep a brownish color. The tendency towards a rusty color, as in non-glaucconitic soils, is much less pronounced, at least in this first stage.

The most important feature of this first stage is the presence in all considered soils of a cutan around every skeleton particle, even between the bands of clay accumulation, which is normally considered as the C-hor. of the profile. However, this phenomenon is highly divergent. In coarse non-glaucconitic sands, the clay cutans are hardly visible in thin sections. In very glauconitic materials, the plasma may be so abundant that it fills an important part of the intergranular space. In the lamellae, one distinctly recognizes concentric clay accumulations, clearly indicating the phenomenon of successive migration.

It is remarkable that in the stratified part of the profile roots are almost entirely lacking. This is in accordance with the idea of Edelman (1960) that the pores in sandy soils with original stratification are too small for roots without the preliminary burrowing of soil fauna.

*Stage B : Homogenization of the profile and formation of secondary clay*

These two phenomena belong to the same process. They will, however, be treated separately for clarity.

*Homogenization*

This phenomenon presents itself in a very heterogeneous way. The lower

limit of the homogenized zone is very irregular and discontinuous : non-homogenized patches are always left in the homogenized zone. It is characteristic that the roots adapt themselves completely to the homogenized zone.

The process of homogenization can take on different aspects according to the nature of the enveloping cutan.

(1) In soils with a cutan of dispersed humus, the homogenization gives rise to a zone of grayish color, often with a pinkish tinge. Consistency is considerably diminished. During the process, dispersed humus is replaced for the most part by moder humus scattered among bleached sand and silt grains. We call these profiles primary podzols.

Up to now, we have had no clear evidence that at the moment of formation of the B2h2-hor. there was already a bleached A2-hor., but we could establish without doubt that the homogenized zone was changing into a bleached horizon.

(2) In soils with a mineral cutan, the homogenization may produce the formation of a brownish or a bleached homogenized zone.

The formation of a *brownish homogenized zone* occurs in dry soils with brownish plasma. The homogenized zone gets a slightly lighter color, the consistency appreciably diminishes and, if the plasma is abundant, the clay content decreases considerably.

In thin sections, a partial disappearance of the continuous oriented cutan from the first stage is observed; parts of the clay cutans remain on the sand grains, so that these grains are partially bleached.

The diminishing consistency seems to be due to the disappearance of the continuous cutan which acts as glue or cement.

The formation of a *bleached homogenized zone* takes place in wet soils with brownish plasma and in all soils with greenish plasma. The homogenization gives rise to a strongly bleached zone, with an ever-decreasing consistency.

In wet soils with brownish plasma, another process takes place at the same time : rusty strips are formed at the margin between the bleached and the stratified zone. In thin sections, it appears to be due to a partial destruction of the clay minerals in the stratified zone and to a translocation of free oxides, especially of iron. This is analogous to the formation of a profile with destroyed textural B-hor., described by Ameryckx (1960) for the soils of the Flemish Sandy Region.

In the upper part of the profile, a few non-homogenized patches are left. These patches are relatively small. Surrounded by a rusty, iron-enriched band, they form indurated mottles and, in extreme cases, iron concretions. Thus, these mottles and iron concretions are remnants of the stratified zone, and are enriched with iron, especially at their peripheries. These iron accumulations consist of intergranular non-birefringent plasma, which owes its micromorphological characteristics to the fact that seemingly unoriented clayish material, mixed with humic and ferric substances, has replaced intergranular filling of a former birefringent kind. The same unoriented clayish material may also fill other intergranular spaces. The problem of either replacement or simple filling still remains open for discussion. Birefringent, well-oriented colloidal material (obviously clay-

ferric complexes) is still present in the form of thin cutans around all of the skeleton particles. In the extreme case of concretions, the intergranular space is almost entirely filled. No plasma is left in the bleached part.

In the soils with greenish plasma it seems that free oxides are not produced at this stage, so that the bleached zone passes directly into the greenish stratified zone.

As a conclusion, it may be said that the homogenization brings about differentiation in the profile. The homogenized zone forms an impoverished horizon compared to the stratified zone; this impoverishment presents important differences according to the cases. In the coarse non-glaucinitic sands with little plasma in the stratified zone, the impoverishment is small. In the glauconitic materials, the difference in clay content may reach several percents and in this case, the profile can be considered as having an A2-hor. overlying a B2t-hor.

In the case of the wet soils, mottling often forms a zone between the bleached A- and B2t-hor. which can be assimilated to a discontinuous B2ir-hor. This B2ir-hor. does not form in the A2-hor., but in the upper part of the B2t-hor. by accumulation of free iron oxides from the A2-hor.

#### *Formation of secondary clay*

We have established that intense translocation of clay from the homogenized zone often produces an accumulation of clay in the root holes at the bottom of the homogenized zone. We have called this "secondary clay", since this form of translocation and accumulation is completely different from the clay enrichment during the first stage. The secondary clay is either grayish in non-glaucinitic materials or greenish in glauconitic materials, even when the primary clay is brownish, probably indicating a reduction process.

This secondary accumulation is especially pronounced in soils with greenish plasma and silty parent material (30–50% of silt). In this case, the accumulation takes place just below the bleached A2-hor. and accentuates the pre-existing difference in clay content between the A2-hor. and the stratified B2t-hor. In such profiles, differences in clay content reaching 20% can be found. (Plate C1.)

In the soils with brownish plasma, the secondary clay accumulation is mainly pronounced when silty horizons are present in the subsoil. These layers are thoroughly interwoven with very small channels, formed by a multitude of rootlets and covered or filled up with clay cutans (Plate C8). Such silty horizons always have a mottled aspect and the hard or firm consistency of a fragipan horizon (Deckers and Baeyens, 1963).

In thin sections, the secondary clay is present in the shape of bulky and localized accumulations, often with concentric forms of superposed layers, and with strong birefringence and distinct extinction bands. All these criteria clearly indicate clay migration (Brewer and Haldane, 1957).

The present state of the profile determines the further development.

#### *Stage C : Formation of an iron or humus B-horizon*

##### *Soils with unbleached homogenized horizon*

In this horizon, a brown diffuse B2ir-hor. is formed. This is probably due



to oxidation or alteration in situ of remnants from the primary clay and of alterable minerals which are still present in the horizon at this stage of development. It is the well-known B2ir-hor. of the brown podzolic soils of the American authors (Frei and Cline, 1949) or of the "Podsol-Braunerde" of German authors (Altemüller, 1962). We normally find this profile in the glauconitic dry soils with brownish plasma where the oxydation of the grains of glauconite, not yet altered in the first stage, is greatly responsible for the brownish color and the relatively high free iron content.

The non-glauconitic dry soils probably had the same stage of development. Yet, presently, they always show a distinct podzol, characterized by a differentiation of the humus accumulation in two distinct horizons, an upper blackish one (B2h1-hor.) and a lower brownish one (B2h2-hor.); there is an abrupt transition between the two horizons, often accentuated by a very thin, very hard iron pan. The B2h1-hor. is strongly impoverished in iron and calcinates white; the B2h2-hor. is not impoverished in iron, but on the contrary often presents a slight accumulation of free iron (De Coninck, 1954). This is probably the remnant of a diffuse B2ir-hor.

In thin sections, the B2ir-hor. of the brown podzolic soil indicates the presence of small floculations of a brown non-birefringent plasma on and between the skeleton grains. It seems to be composed of ferro-organic compounds. We also find much mull-like moder formed by root decomposition.

In the B2h1-hor. of the humus podzol, the organic matter is composed of moder and dispersed humus (Edelman, 1960). The moder is formed by decomposition of the roots, the development of which is very intense in this horizon. These are the pellets of the American classification (1960).

The thin iron pan presents a very abundant, dark brown, non-birefringent plasma (Plates C6 and C7), which fills most of the pore space. The great content of organic matter in this horizon points out that it probably consists of ferro-organic compounds.

The organic matter of the B2h2-hor. is chiefly composed of dispersed humus; however, there is always an appreciable amount of moder humus.

#### *Soils with bleached homogenized horizon*

In these soils, B2ir-hor. formation is impossible in the bleached A2-hor. due to a lack of alterable substances. A brown podzolic soil with B2ir-hor. is never found. There can only be translocation of organic matter, which always forms a very diffuse illuviation. First, a brown or reddish-brown horizon of dispersed humus originates; in a second stage, a grayish-brown horizon appears in the upper part of the B2h-hor. by replacement of the dispersed humus by root-moder. The color of this horizon evolves into pinkish gray. The transition between the two horizons is very gradual. In some profiles, we could even find the whole B2h-hor. chiefly composed of root moder.

In the soils with rusty mottles and concretions (discontinuous B2ir-hor.) the B2h-hor. can be formed just over and between these iron accumulations. Such profiles can be considered as having a B2h- and a B2ir-hor., the last one being discontinuous. But strictly speaking, the B2ir-hor. formation is not involved in the process of podzolisation.

Chemical analyses of the iron concretions give a relatively high organic



matter content (2–3%). We suppose that this organic matter originated from root decomposition and formed compounds with the iron oxides during the homogenization.

A similar process may occur in soils with greenish plasma; the B2h-hor. then develops between and around the remnants of the greenish B2t-hor.

#### *Stage D : Formation of mottles and concretions*

In many soils with greenish plasma - and only in these soils - we find numerous mottles and concretions in the A2-hor. in the zone of contact between the A2- and the B2t-hor.

The study of thin sections shows that this is not a question of iron translocation and accumulation, but alteration in situ, probably an oxydation, of the greenish plasma. During the transition, the color gradually passes from greenish to brownish or to reddish-brown, while the birefringence decreases in the same way and disappears almost completely in the mottles and concretions (Plates C2–5). This phenomenon, however, is not going on in all soils with greenish plasma; up to now, we have not found an explanation for this difference.

#### DESCRIPTION OF SOIL PROFILES<sup>1</sup>

The descriptions are to be an illustration of the preceding chapter. These profiles represent the most important in the described sequences<sup>2</sup>:

(1) A dry profile on non-glaucous sand with a podzol having a B2h1-hor. and a B2h2-hor. separated by a thin iron pan, and a C-hor., differentiated into a homogenized C1-hor. and a stratified C2-hor.

(2) A dry profile on non-glaucous sand with slight evidences of free oxide formation and strong secondary clay illuviation in a silty subsoil layer.

(3) A wet profile on non-glaucous loamy sand with a discontinuous B2ir-hor., composed of indurated rusty mottles and concretions, and with an incipient formation of a B2h-hor.

(4) A toposequence on glaucous loamy sand going from a dry to a wet profile. The dry profile has a brown podzolic B2ir-hor., which is formed in the homogenized zone and shows typical primary clay illuviation bands in the stratified zone. The wet profile has a B2h-hor. in the bleached homogenized A2-hor. and shows a discontinuous B2ir-hor. overlying the stratified zone, and secondary clay illuviation in the more silty subsoil.

<sup>1</sup> According to the Soil Survey Staff, U.S.D.A. (1960), profiles 1 and 2 are orthumods, 3 and 4A ferraquods, and 4B and 5 humaquods (Ed.).

<sup>2</sup> Another paper dealing with "Pedogenèse dans des sols sableux glaucousifères" was presented at the VIIIth International Congress of Soil Science, held in Bucarest (1964). This deals mostly with similar profile descriptions, emphasizing those of strongly glaucous materials.

*Profile 1: Dry profile on non-glauciferous coarse sand*

Locality: Sheet of Iepenrooy, municipality of Meer (northern Campine). Vegetation: Natural vegetation of *Calluna vulgaris*, *Pinus silvestris*, *Betula*, *Quercus*, mosses. (Fig.2).

Macromorphology

- <2-0 cm: O1, little altered plant remains of *Calluna* and many bleached sand grains;
- 0-3/4 cm: A1, very dark gray (10 YR 2/1<sup>1</sup>) bleached sand<sup>2</sup>; humic; structureless, massive; very friable;
- 3/4-15/20 cm: A2, grayish-brown to dark grayish-brown (10 YR 3/2-4/2) bleached sand; little humic; structureless, single grain: loose to very friable; with few, faint to distinct, irregular, very dark gray (10 YR 3/1) humic patches;
- 15/20-23/30 cm: B2h1, black (5 YR 2/1) sand; very humic; structureless, massive; firm; with many thin rootmats and bleached sand grains in the mats; thick, dark reddish-brown (5 YR 3/2) rootmat and iron pan at the lower boundary;
- 23/30-30/35 cm: B2h2, dark reddish-brown to black (5 YR 2/2-2/1) sand: humic; without bleached sand grains; structureless, massive; friable to firm; very few roots;
- 30/35-50/55 cm: B3h, dark reddish-brown (5 YR 3/5-3/2) sand; humic; structureless, massive: friable; with many, very irregular, darker humic lamellae and spots;
- 50/55-65/75 cm: C1, variegated sand, dark brown (7.5 YR 3/2 and 10 YR 4/4) and yellowish-brown (10 YR 5/4) irregular spots; structureless, massive; loose to very friable; with few, thin, humic, slightly firmer lamellae and some round, dark reddish-brown (5 YR 3/3) spots, filled up with dead roots and organic matter;

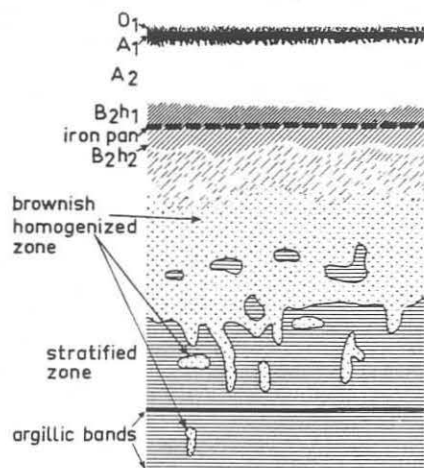


Fig.2. Profile 1.

<sup>1</sup> Color notations according to Munsell Soil Color Charts. All colors are given for moist soil materials.

<sup>2</sup> Textural class is given according to the Belgian texture classification.

- >65/75 cm: C2, light yellowish-brown to brownish-yellow (10 YR 6/4-6/6) sand; structureless, massive; very friable, firmer than the C1-hor.; stratified with (1) medium and large, distinct (especially when dry), yellowish brown (10 YR 5/4) (when dry, color shows lighter than in the matrix) spots, which are distinctly looser; the extent of these spots gradually diminishes to the bottom; all the roots are present in these loose spots; (2) very irregular humic lamellae and humic spots; (3) brown to dark brown (7.5 YR 4/4) B2t-hor. lamellae, firm when wet, very hard when dry, discontinuous in the upper part (breakdown of the B2t-hor.) and forming "double bands" with the humic lamellae.

#### Micromorphology

In the horizons A1, A2 and B2h1, the organic matter is chiefly composed of moder humus between bleached sand grains. Especially in the B2h1-hor., the accumulation of rootmoder humus is very important. Just above the boundary with the B2h2-hor., a mineral skeleton is lacking almost entirely; we have only unaltered root remains and root-moder. Often the excrements are present around and in the root remains, indicating undoubtedly that the moder is formed by small soil fauna from the root remains. The excrements show a strong tendency to form clusters and to pass into dispersed humus.

In the iron pan, the intergranular space is entirely filled up with a non-birefringent plasma, consisting primarily of free oxides and of organic matter.

In the B2h2-hor., mineral skeleton prevails, while organic plasma fills most of the pores, especially in the upper part. Around the sand grains we find thick continuous cutans of dispersed humus, forming bridges at contact points of the grains. In the intergranular space, great quantities of moder, illuviated or formed in place, are present.

The argillic lamellae show two forms of plasma: there is a thin, strong birefringent cutan on the skeleton, while an important part of the intergranular space is filled with birefringent plasma, often with the typical indication of successive layering.

#### Profile 2: Dry profile on non-glaucous sand with silty layer in the subsoil

Locality: Sheet of Iepenrooy, municipality of Meer (northern Campine). Vegetation: Natural vegetation of *Calluna vulgaris*, *Molinia coerulacea*, *Quercus*, *Betula*, *Pinus silvestris*, little *Erica* and *Genista*, mosses. (Fig.3.)

#### Macromorphology

- <1-0 cm: O1, little altered plant remains and many bleached sand grains;  
 0-25 cm: A2, dark gray to very dark gray (10 YR 4/1-3/1) sand, humic; structureless, massive; loose; with very dark gray (10 YR 3/1), common, distinct, diffuse, medium and coarse patches and strips;  
 25/30-30/40 cm: B2h1, very dark gray (5 YR 3/1) sand, very humic; many bleached sand grains; structureless, massive; firm; with few bleached A2-hor. patches; abrupt, irregular boundary, coinciding with a very hard, reddish-brown (5 YR 2/2), thin iron pan, underlying a distinct rootmat;  
 30/40-50/60 cm: B2h2, variegated sand: matrix very dark brown (7.5 YR 2/2); yellowish-red (5 YR 4/6) little spots and horizontal strips just underneath the iron path (remains of an earlier B2ir-hor.); dark yellowish-brown (10 YR 3/4); brown (10 YR 5/3); dark brown to very dark gray (7.5 YR 3/3); structureless, massive; very friable (dark parts), loose (light parts); light patches form irregular cavities and holes in the dark matrix;  
 50/60-75 cm: B2ir, mottled sand: matrix yellowish-brown (10 YR 2.5 Y 5/4);

structureless, massive; friable; non-stratified; with many, distinct, medium and coarse, diffuse to clear, very hard mottles, reddish-brown to dark reddish-brown (7.5-5 YR 4/4), with many black spots and faint stratification; remark : mottles form a discontinuous B2ir-hor.;

- 75-80 cm: C, yellowish-brown (10 YR-2.5 Y 5/4) sand; structureless, massive; friable; non-stratified; with (1) common, faint, medium and coarse, diffuse, yellowish-brown (10 YR 5/4) patches, which are the continuation of the pale patches of the B2h2-hor., with still more friable consistency than matrix; locally brown to dark brown (10 YR 3/3-3/4), slightly humic material around these patches; (2) brown to dark brown (10 YR 3/3-3/4) humic patches; (3) common, faint, little to coarse, diffuse, firm, dark yellowish-brown (10 YR 4/4) stratified patches;
- 80-90/95 cm: B2t, pale brown (10 YR 6/3) sand; structureless, massive; loose; with many, prominent, medium and coarse, sharp, firm, strong brown (7.5 YR 5/6), stratified patches, locally occupying the largest part of the horizon; the strong brown patches form the remnants of a former continuous B2t-hor.;
- 90/95-100/105 cm: II B2t, variegated light sandy loam : light gray (2.5 Y 7/2: type 1); light brownish-gray (2.5 Y 6/2; type 2); strong brown (7.5 YR 5/8: type 3); these three components show a regular arrangement : the upper part consists of 1 and 2, with 1 above and 2 beneath; next a discontinuous 3 band, again a 1 band, a thick 2 band, an irregular 3 band, again a (1+2) band with 2 prevailing in the central and bottom part; the whole horizon is structureless and massive; the three components exhibit a difference in composition and consistency : 1 is

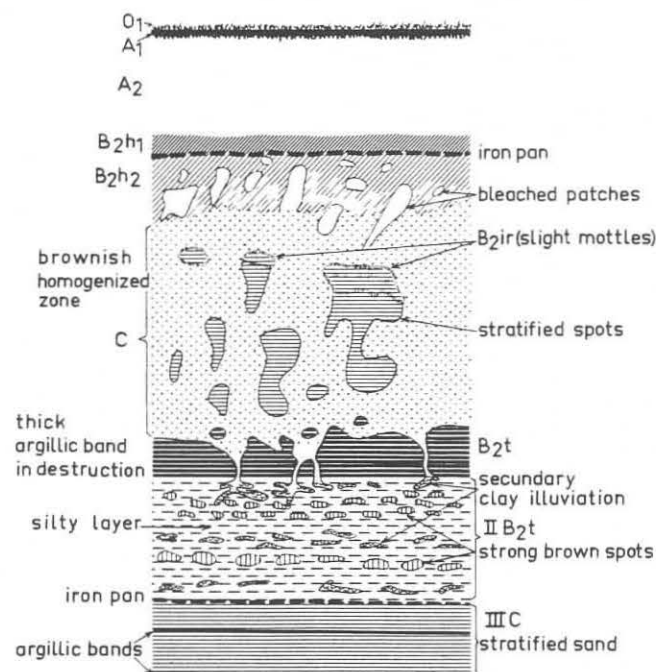


Fig.3. Profile 2.

- silty, friable, non-sticky and non-plastic; 2 is more clayey because of thin irregular clayey channels, friable to firm, slightly sticky and slightly plastic, with many dead roots; 3 is silty, stratified, friable to firm, non-sticky, non-plastic and more brittle; the lower boundary is abrupt, accentuated by a very hard iron pan formed by successive horizontal thin yellowish-red (5 YR 4/8) layers of free oxides;
- >100/105 cm: III C, yellowish-brown (10 YR 5/4) sand, stratified, structureless, massive; very friable; with irregular strong brown (7.5 YR 5/8) argillic bands.

This profile is in the first place an illustration of the primary B2t-hor. destruction and of the illuviation of secondary clay in a silty layer. This silty layer causes a slight water retention, probably causing the formation of little mottling in the profile (discontinuous B2ir-hor.)

#### Micromorphology

The A1-hor. has moder humus with a tendency to formation of clusters (first stage of dispersed humus). All the skeleton grains are bleached. In the A2-hor., we find the same skeleton with scattered moder humus between and on the skeleton grains, with a tendency to grow together to compact clusters (disappearance of the original excrements structure). In a few places, fresh excretions are present in cavities of not-yet-altered plant remains.

In the B2h1-hor., the intergranular spaces are for the most part filled with rootmoder and illuviated moder. A large part of this moder has lost its original shape to form compact black clusters and shapeless aggregates enclosing the most part of the skeleton.

In the B2h2-hor., the skeleton is fully enveloped with a brown continuous cutan of dispersed humus and with root moder (few little iron concretions were also found). The most striking differences between the B2h1-hor. and B2h2-hor. are the color (black in the B2h1-hor. and brown in the B2h2-hor.) and the way in which the skeleton is coated (more complete in the B2h2-hor.)

In the B2ir-hor., the skeleton is fully enveloped with thin cutans, with more or less distinct birefringence. There are also a number of brown birefringent plasma concentrations but of amygdalus type, which are an indication of pseudogley conditions.

The micromorphology of the C-hor. indicates a loose structure, composed of grains more or less enveloped with birefringent plasma, but practically without intergranular braces. A few little-iron concentrations are present.

The destroyed B2t-hor. shows localised strong birefringent pore fillings often with layered structure. Little slightly birefringent or opaque iron concentrations show pseudogley conditions.

In the B2t-hor., we find bulky, localised clay illuviation. The color is grayish, with high birefringence, indicating reducing circumstances. Their localisation follows large conducting channels, but penetrates also deeply between the skeleton grains. Around the skeleton, a thin light-colored birefringent plasma is present.

The iron pan at the lower boundary has abundant non-birefringent plasma, filling up a large part of the porespace. It seems to be built up of goethite and hematite.

#### Profile 3: Wet profile on non-glaucinitic loamy sand

Locality: Sheet of Brecht, municipality of Brecht/Overbroek (northern Campine). Vegetation: Plantation of *Pinus silvestris*. (Fig.4.)

#### Macromorphology

- <2-0 cm: 01, accumulation of needles of *Pinus silvestris*;

- 0-25/35 cm: Ap, variegated plow layer;  
 25/35-35/60 cm: A2+B2h, variegated loamy sand, pale brown (10 YR 6/3), brown to dark brown (7.5 YR 4/2) and dark grayish-brown (10 YR 4/2); structureless, massive; friable, with few distinct, common, friable to firm, strong brown (7.5 YR 5/6) mottles and concretions;  
 35/60-50/70 cm: B2ir + B2h, composed of three different materials : (1) strong brown (7.5 Y 4/6) and dark reddish-brown (5 YR 3/4 and 5 YR 3/2), structureless, massive, extremely firm, large concretions, the number of which increases from the top to the bottom; (2) dark reddish-brown (5 YR 3/2), structureless, massive, friable to firm, irregular, humic patches and horizontal, thin, humic lamellae; (3) brown (10 YR 5/3), structureless, massive, friable patches;  
 >50/70 cm: Cg, stratified horizontal layers, consecutively strong brown (7.5 YR 5/6) and pale gray to pale yellow (2.5 Y 6/2-6/4), structureless, massive, friable; locally pale brown (10 YR 6) patches and tongues.

In this profile the stratified zone has a rusty color; at the top of this zone, a discontinuous B2ir-hor. composed of extremely firm concretions is present. Between these concretions, a faint B2h-hor. is formed.

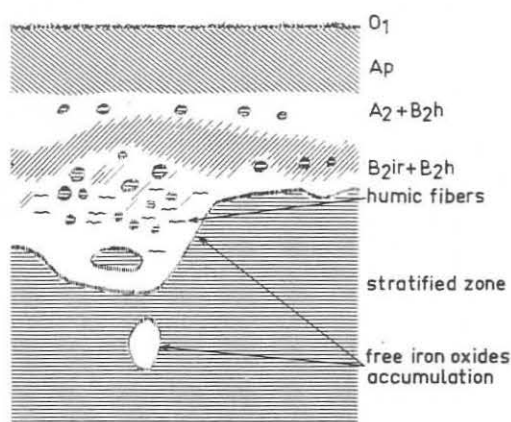


Fig.4. Profile 3.

#### Micromorphology

The humic part of the A2+B2h-horizons is composed of rather indistinct, scattered agglomerations of mullic moder. In the A2 part, localized cutans of more or less birefringent plasma are present. This is probably a remnant of a primary clay cutan.

The B2ir-hor. concretions show two distinctly different forms of plasma : (1) most of the skeleton grains are coated with birefringent, yellowish-brown cutans; (2) many intergranular spaces are filled with non-birefringent, yellowish-brown to brownish-red plasma, composed of ferro-organic compounds. This difference can only be explained by two subsequent stages of formation.

In the Cg-hor. the birefringent cutan around the skeleton grains is present everywhere, while non-birefringent intergranular plasma is lacking almost entirely.

#### Profile 4: Toposequence on glauconitic loamy sand

Locality: Sheet of Geel, municipality of Olen (southern Campine).



*Dry profile*

Vegetation: Plantation of *Pinus silvestris*; undergrowth of *Festuca rubra*, *Descampsia flexuosa*, *Agrostis stolonifera*, *Luzula*, *Genista*, *Calluna vulgaris*, *Betula*, *Quercus*. (Fig.5.)

## Macromorphology

- <4-0 cm: 01, unaltered and slightly altered plant remains;  
 0-25/27 cm: Ap, brown to dark brown (10 YR 5/3-4/3) loamy sand, humic; structureless, massive; very friable; small pieces of charcoal and bricks;  
 25/27-45 cm: B2ir, dark yellowish-brown (10 YR 4/4) loamy sand; structureless, massive; friable;  
 45/75 cm: C1, light yellowish-brown (2.5 Y 6/4) sand; structureless, massive; loose to very friable; non-stratified; with common, faint, clear, light olive brown (2.5 Y 5/4-5/6) stratified patches with slightly firmer consistency; on breaking, these patches form angular fragments, while the matrix forms rounded ones; roots are present only in matrix;  
 >75 cm: C2, light olive brown (2.5 Y 6/4-5/6) sand; structureless, massive; very friable; stratified; with (1) horizontal, prominent, stratified, sharp, yellowish-brown to dark yellowish-brown (10 YR 5/6-6/4), structureless, massive, friable to firm, (very hard when dry), 0.5-2 cm thick argillic bands, partially destroyed in the upper part; (2) faint, many, fine to coarse, clear, light yellowish-brown (2.5 Y 6/4), loose to very friable, irregular pale olive (5 Y 6/3) spots that are bordered by strong brown (7.5 YR 5/6-5/8) strips and patches with firmer consistence; where these spots cut the argillic bands, the latter get a strong brown color and firm to very firm consistency; roots are only present in these looser spots.

*Wet profile*

Vegetation: Plantation of *Pinus silvestris*; undergrowth of *Festuca rubra*, *Descampsia flexuosa*, *Agrostis stolonifera*, *Luzula*, *Genista*, *Calluna vulgaris*, *Betula*, *Quercus*.

## Macromorphology

- 0-45/55 cm: Ap, dark brown (10 YR 3/3) loamy sand, humic; structureless, massive;  
 45/55-70/75 cm: B2h, variegated loamy sand; structureless, massive; (1) matrix dark reddish-brown (5 YR 3/2), very friable; (2) dark brown (10 YR 3/3), loose to very friable, forming distinct, sharp, very irregular patches; (3) little, faint, sharp, rusty spots and a few dark reddish-brown (5 YR 3/3) very firm concretions, forming discontinuous horizontal bands (remnants of argillic lamellae); the lighter patches pass into the A2-hor. material;  
 70/75-95/100 cm: A2, variegated loamy sand; structureless, massive: (1) yellowish-brown to light olive brown (10 YR 2.5 Y 5/6), friable; (2) light olive brown (2.5 Y 5/4), more friable; the two materials form faint, diffuse patches among each other; with many rusty spots and dots and a few firm concretions;  
 95/100-110/115 cm: B2ir, composed of two materials: (a) variegated loamy sand; structureless, massive; friable to firm according to the darkness

of the color: stratified; (1) dark yellowish-brown (10 YR 4/4); (2) yellowish-red (5 YR 4/6); (3) locally reddish-brown to dark reddish-brown (5 YR 4/4-3/4), forming thin horizontal layers; (b) idem as the A2-hor. with more rusty spots : at the boundary of (a) and (b) thin reddish-brown to yellowish-red (10 YR 4/4-4/8) layers or strong brown (7.5 YR 5/6) non-stratified, more friable material;

110/115-150/160 cm: Cg, light olive brown (2.5 Y 5/6-5/4) loamy sand; structureless, massive; friable; stratified; with (1) many, prominent, coarse, sharp to diffuse, irregular, loose, pale olive to olive (5 Y 6/3-5/3), non stratified patches; locally these spots feel a little more clayey and are more olive in color (5 Y 6/4-5/4); (2) dark yellowish-brown (10 YR 4/4), yellowish-red (5 YR 4/6), reddish-brown to dark reddish-brown (5 YR 4/4-3/4) mottles, strips and circlets; (3) in the whole horizon, but especially in the rusty part, many black and dark brown dots; the thin silty layers grow thicker and more numerous downwards;

>150/160 cm: IIB2t, yellowish-brown (10 YR 5/6) loamy sand to light sandy loam; structureless, massive; friable; stratified; with distinct, many, fine to coarse, diffuse, green, clayey, slightly plastic, non-stratified patches; in the core of these patches, olive (5 Y 7/4), loose, non-stratified material may be present.

This toposequence illustrates very well on the one side the formation of a brownish homogenized zone with a diffuse, continuous B2ir-hor. in the dry soil. On the other side, the presence of a bleached A2-hor. with a B2h-hor. and a discontinuous B2ir-hor. at the top of the stratified zone are found in the wet soil; a silty layer in the subsoil with green secondary clay has to be pointed out. In the zone of transition between the two described profiles, the homogenized zone grows gradually more bleached from dry to wet with a disappearance of the diffuse B2ir-hor. and the appearance of a discontinuous B2ir-hor.

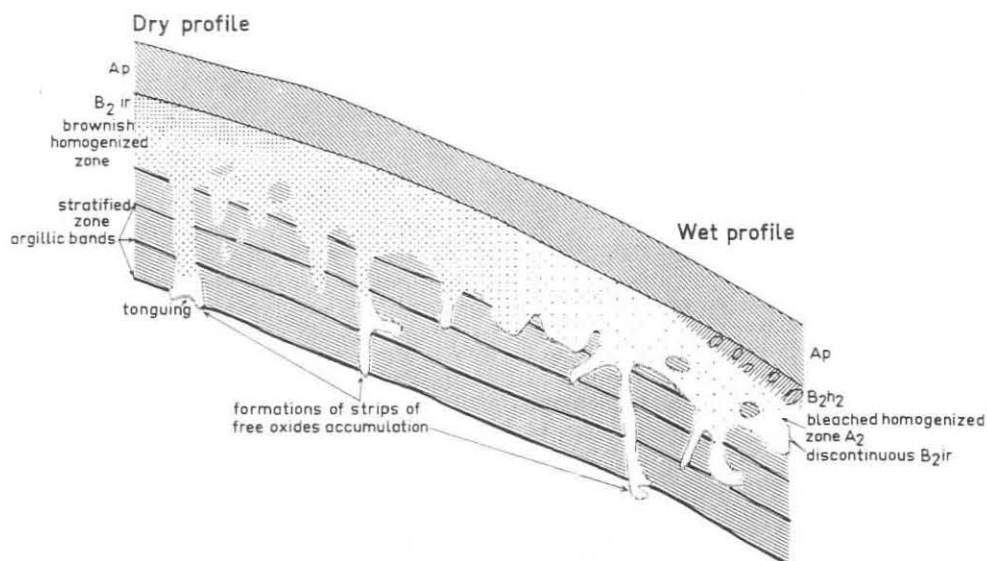


Fig.5. Toposequence (4).

## Micromorphology

Dry profile: In the B2ir-hor. the skeleton is partially enveloped by a dark brown plasma cutan in which the birefringence, present in underlying horizons, has mostly disappeared. Some non-birefringent intergranular fillings are found. This opaque plasma is formed by alterations of the birefringent plasma. Locally it has a loose structure, probably indicating organo-ferric compounds.

In the homogenized and stratified part of the C-hor., little difference is visible in the nature and volume of the birefringent plasma.

In the B2t bands, an abundant birefringent plasma envelops the whole skeleton, often forming successive layering.

Wet profile: In the B2h-hor. the skeleton is partially enveloped with dispersed humus and loose rootmoder accumulations.

In the A2-hor., many grains are still surrounded by a thin, slightly birefringent cutan. The glauconite grains show different colors, according to the stage of alteration.

In the B2ir-hor. matter, a partially birefringent cutan is present around a part of the skeleton grains. Locally, non-birefringent plasma fills the intergranular space. The rusty dots are formed by brown or dark brown altered opaque glauconite grains.

In the stratified Cg-hor., the cutan is more distinct and more birefringent than in the B2ir-hor., indicating that in the last horizon an alteration of the primary cutan is going on.

In the silty II Cg-hor. the plasma fills most of the intergranular space. It is highly birefringent with clear extinction bands. Locally, the birefringence diminishes, while the color turns a darker brown, indicating the beginning of an alteration.

*Profile 5: Wet profile on glauconitic sand with primary podzol*

Locality: Sheet of Grobbendonk, municipality of Grobbendonk (southern Campine). Vegetation: Plantation of *Pinus silvestris*, with *Molinia coerulea*, *Erica tetralix*, *Descampsia flexuosa* and a few mosses. (Fig.6.)

## Macromorphology

- |             |   |
|-------------|---|
| <2/3-0      | cm: 01, little altered needles;   |
| 0-20/25     | cm: A2, very dark gray (10 YR 3/1) sand, humic: structureless, massive; very friable to loose; with (1) many, very dark gray to black (5 YR 3/1-2/1) spots and vertical strips (rootholes); (2) many, faint, diffuse, looser, dark grayish-brown to dark gray (10 YR 4/2-4/1) patches, especially in the bottom part;   |
| 20/25-35/40 | cm: B2h1, very dark to black (5 YR 3/1-2/1), rubbed dark reddish-brown (5 YR 3/2), passing downwards to dark brown (5 YR 3/2), sand, very humic: structureless, massive; friable; with (1) many, faint, diffuse, looser and less humic, dark brown (7.5 YR 3/2) patches; (2) many dark spots and strips like those in A2;   |
| 35/40-45/65 | cm: B2h2, dark reddish brown (5 YR 3/3-3/2) passing downwards to dark reddish-brown (5 YR 3/3) sand, humic, without bleached sand grains: structureless, massive; locally friable, locally very firm stratified lumps, separated by planes with plenty of roots; with irregular, darker humus fibers and rootmats; many roots in the loose part, no roots in the firm lumps;                                  |
| 45/65-75/80 | cm: B3h1, dark yellowish-brown (10 YR 4/4) sand: structureless, massive; friable; stratified; with (1) little and coarse, faint, diffuse, looser, yellowish-brown to dark yellowish-brown (10 YR 5/6-4/4) patches, especially in the upper part in which only roots are present; (2) humic fibers closely following the stratification; (3) firmer, dark brown (7.5 YR 3/1) humic band at the lower boundary; |

- 75/80–100 cm: II B3h2, olive brown to dark yellowish-brown (2.5 Y–10 YR 3/4) sand, structureless, massive; firm; stratified; with a few, faint, humic fibers, especially in the upper part; roots are lacking entirely; many little cobbles at the lower boundary;
- >110 cm: III Cg, green stratified very glauconitic sand.

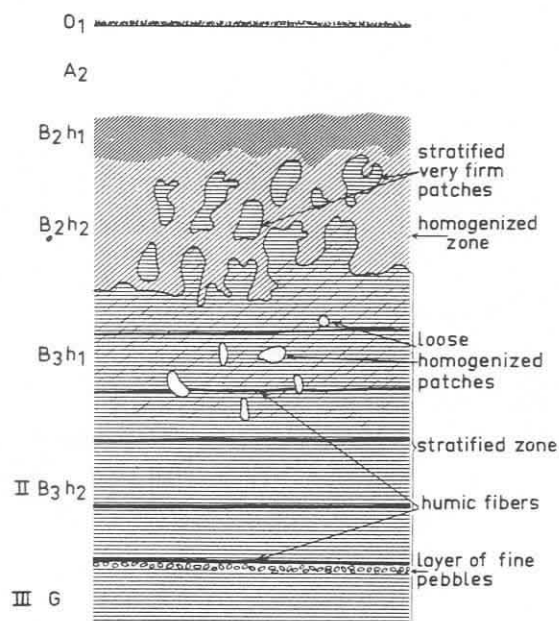


Fig.6. Profile 5.

#### Micromorphology

The A2-hor. shows residual discontinuous, brown, non-birefringent, humic plasma.

In the B2h2-hor., important cutans and intergranular fillings of dispersed humus are present. Locally, rootmoder is found. The numerous glauconite grains are freshly green and show no alteration at their periphery. In the humic bands, the cutans of dispersed humus are still more continuous.

The micromorphology of the homogenized and stratified parts of the B3h-hor. shows little or no differences. The glauconite grains can show a transition to a brown color, especially at their periphery. Nowhere do they pass into a colloidal form.

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## SUMMARY

A genetic classification of sandy soils of the Belgian Campine based on field observation and micromorphology is attempted. The southern part of this region has a glauconitic parent material which has a great influence on the soil development.

Analogous stages of development can be distinguished. The intensity of these stages determines the final composition of the profile.

In all considered soils, a colloidal cutan is formed around the skeleton particles. This cutan can be organic or mineral, it is a "primary podzol" in the case of an organic cutan, and a "primary clay" in the case of a mineral cutan (stage A).

Stage B coincides with the homogenization of the profile (disappearance of the original stratification) and a translocation of clay (secondary clay) which brings about a textural differentiation in the profile.

Stage C shows the development going on in the homogenized zone. When it has a brownish color, the sequence of development is first a diffuse B2ir-hor., then a humic podzol with iron pan and iron accumulation in the bottom part of the B2h-hor. When the homogenized zone is completely bleached, only organic accumulation is present.

Stage D is restricted to some profiles on glauconitic material, where the alteration of the birefringent cutan gives rise to mottles and iron concretions.

Four profiles and a toposequence are described. The most important micromorphological features are discussed.

## REFERENCES

- Altemüller, H.-J., 1962. Beitrag zur mikromorphologischen Differenzierung von durchschlämmter Parabraunerde, Podsol-Braunerde und Humus-Podsol. In: Arbeiten aus dem Gebiet der Mikromorphologie des Bodems. Chemie Verlag, Weinheim/Bergstrasse.
- Ameryckx, J., 1960. La Pédogénèse en Flandre sablonneuse. *Pédologie*, 10 (1) : 124-190.
- Brewer, R. and Haldane, A.D., 1957. Preliminary experiments in the development of clay orientation in soils. *Soil Sci.*, 84 : 301-309.
- Brewer, R., 1960. Cutans: Their definition, recognition, and interpretation. *J. Soil Sci.*, 11, 280-292.
- Deckers, J. en Baeyens, L., 1963. Polysequumprofielen van de Hoge Kempen. *Pedologie*, 13 (1) : 120-154.
- De Coninck, F., 1954. Différences dans la morphologie des podzols suivant l'humidité (Campine Anversoise). *Trans. Intern. Congr. Soil Sci.*, 5th, Leopoldville, 4 : 412-417.
- De Coninck, F. et Laruelle, J., 1960. L'influence de la composition minéralogique sur la formation des podzols. *Trans. Intern. Congr. Soil Sci.*, 7th, Madison, 1960, 5 (22) : 157-164.
- Edelman, C.H., 1960. Podzols forestiers et podzols de bruyère. *Pédologie*, 10 (2) : 229-249.
- Frei, E. and Cline, M.G., 1949. Profile studies of normal soils of New York. *Micromorphological studies of the gray-brown podzolic-brown podzolic soil sequence.* *Soil Sci.*, 76 : 333-344.
- Hoeksema, K.J., 1953. De natuurlijke homogenisatie van het bodemprofiel. *Boor Spade*, 6 : 24-30.

- Jongerius, A., 1957. Morfologische onderzoeken over de bodemstructuur. Mededel. Sticht. Bodemkartering, Bodemkundige Studies, 2 : 156 pp.
- Kubiena, W.L., 1938. Micropedology. Collegiate Press, Ames, Iowa, 243 pp.
- Soil Survey Staff U.S.D.A., 1960. Soil Classification, a Comprehensive System. 7th Approximation. Soil Conservation Service, U.S. Dept. Agr., Washington, D.C., 265 pp.
- Soil Survey Staff U.S.D.A., 1951. Soil Survey Manual. U.S. Dept. Agr., Washington, D.C., 503 pp.

#### COLOURED ILLUSTRATIONS

Plate C1. Greenish B2t-hor. in very glauconitic material: abundant strongly birefringent plasma, filling up all the pore space. At the lower boundary concentric secondary clay accumulations.

Thin section 223, crossed nicols; x 45.

Plate C2. Formation of an iron concretion in non-glauconitic sand. All the pore space has been filled with non-birefringent dark brownish plasma (left part). Between the non-birefringent plasma and the skeleton grains, and in the right part, the primary birefringent cutan is visible.

Thin section 206, plain light; x 27.

Plate C3. Same view as Plate C2. Crossed nicols; x 27.

Plate C4. Formation of a concretion in soils with greenish plasma by alteration of the greenish birefringent plasma (right) to brownish non-birefringent plasma (left).

Thin section 238, plain light; x 45.

Plate C5. Same view as Plate C4. Crossed nicols; x 45.

Plate C6. B2ir of brown podzolic soil on glauconitic sand with thin non-birefringent plasma of organo-ferric compounds. Glauconitic grains in different stages of alteration: from greenish to brownish, showing a gradual lowering of the birefringence.

Thin section 232, plain light; x 45.

Plate C7. Same view as Plate C6. Crossed nicols; x 45.

Plate C8. Strongly birefringent secondary clay illuviation along a root hole.

Thin section 239, crossed nicols; x 45.



